PATENT SPECIFICATION (11) 1 582 589

1 582 589

(21) Application No. 50811/77 (22) Filed 6 Dec 1977
(31) Convention Application No's 789059 (32) Filed 20 Apr 1977 in (19)
789058
789057
(33) United States of America (US)
(44) Complete Specification Published 14 Jan 1981
(51) INT. CL.³ G01N 23/204 23/22
(52) Index at Acceptance G1A A11 A4 C3 C4 C8 CK D12 G12 G16 G17 G1 G2 G5 G7 P5 R2 RX S12 S3 S6 S7 T14 T23 T3

(54) EARTH FORMATION POROSITY LOG USING MEASUREMENT OF NEUTRON ENERGY SPECTRUM

(71) We, TEXACO DEVELOPMENT CORPORATION, a Corporation organized and existing under the laws of the State of Delaware, United States of America, of 135 East 42nd Street, New York, New York 10017, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to radiological well logging methods and apparatus for investigating the characteristics of subsurface earth formations traversed by a borehole, and more particularly, to methods and apparatus for measuring the porosity of each formations in the vicinity of a well borehole by means of neutron well logging techniques.

In the search for hydrocarbons beneath the earth's crust one of the parameters which must be known about an earth formation before evaluating potential is the fractional volume of fluid filled pore space, or porosity, present around the rock grains comprising the earth formation. Several techniques have been developed in the prior art to measure earth formation porosity in a borehole environment. One such technique employs a gamma ray source and a single, or multiple, detectors to measure the electron density of the earth formation by gamma ray scattering. This leads to an inferential measurement of the porosity of the formations. Another technique employs an acoustic transmitter and one or more acoustic receivers. The velocity of sound transmission through the formation from the acoustic transmitter to the receivers is then measured and this quantity can be related to the porosity since sound travels faster in less porous rocks than in fluid filled pore spaces in the earth formations.

A third commercial technique which has been empoyed in the prior art to measure the porosity of earth formations employs a neutron source and either a neutron or gamma ray detector sensitive to low energy, or thermalized, neutron density. Hydrogen is the principal agent responsible for slowing down neutrons emitted into an earth formation. Therefore, in a formation containing a larger amount of hydrogen than is present in low porosity formations the neutron distribution is more rapidly slowed down and is contained in the area of the formation near the source. Hence, the counting rates in remote thermal neutron sensitive detectors located several inches or more from the source will be suppressed. In lower porosity formations which contain little hydrogen, the source neutrons are able to penetrate further. Hence, the counting rates in the detector or detectors are increased. This behaviour may be directly quantified into a measurement of the porosity via well established procedures.

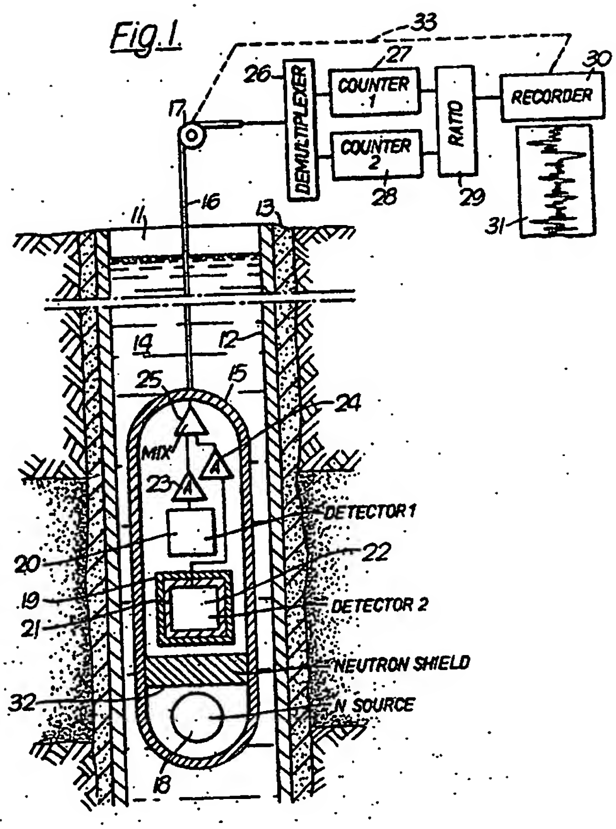
All of these commercially employed methods have generally not proven to be as accurate as desirable due to diameter irregularities of the borehole wall, variation of the properties of different borehole fluids, the irregular cement annulus surrounding the casing in a cased well borehole, and the properties of different types of steel casings and formation lithologies which surround the borehole. For example, the thermal neutron distribution surrounding a source and detector pair sonde as proposed in the prior art can be affected by the chlorine content of the borehole fluid. Similarly, lithological properties of the earth formations in the vicinity of the borehole, such as the boron content of these formations, can affect the measurement of thermal neutron populations. The present invention however, rather than relying on a measurement of the thermal neutron population comprises in preferred forms a neutron measurement of the formation porosity which utilizes a measure of the epithermal neutron population at one detector and the fast neutron population at a second detector spaced approximately the same distance from a neutron source. The fast neutron population may be detected directly by means of a fast neutron detector or indirectly by means of an inelastic gamma ray detector. The fast neutron population may be background corrected. Special detectors and other means may be utilized to effectively discriminate against the detection of

1582589 COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig. 1.



present herein, for a programmer of ordinary skill to program such a small general purpose digital computer using a common compiler language such as FORTRAN and utilizing conventional mathematical interpolation procedures to perform this porosity calculation from the calibration charts in the manner described.

A further embodiment of well logging apparatus in accordance with the present invention will now be described, with reference again to Figures 6 to 9. In this further embodiment the first detector 20 of Figure 6, which is a scintillation type fast neutron detector, is replaced by an inelastic scattering gamma ray detector. This detector may comprise a scintillation type detector which is sensitive to the interaction with the scintillator material of gamma rays produced by the inelastic scattering of fast neutrons by the material comprising the earth formations. Such a detector could comprise, for example, a thallium-doped sodium iodide crystal detector which is sensitive to high energy gamma ray interaction. Such scintillation detectors may also be sensitive to high energy gamma radiation produced by the capture of neutrons from the neutron source in earth formations surrounding the well borehole. However, the background correction techniques described above in connection with Figure 6 and 7 can be used to correct for such thermal neutron capture gamma rays. This technique is based on separating the inelastic scattering gamma rays from capture gamma rays by time separation. This is possible because the inelastic gamma rays will generally only exist during a neutron burst, while the capture gamma rays will persist after the neutron burst and thus can be sampled subsequently.

It will be appreciated that the electrical signals from the inelastic gamma ray detector are similar to the electrical signals from the fast neutron detector 20 and are processed by the remainder of the illustrated system in the same manner as described above in connection with Figures 6 to 10. The respective counters 75, 77 and 76 in this embodiment thus provide counts of the number of inelastic scattered gamma rays caused by the fast neutrons present in the vicinity of the detector 20, background counts due to capture gamma rays resulting from lingering thermal neutrons in the vicinity of the detector 20, and epithermal neutrons present in the vicinity of detector 22, in the form of digital counts. It will be appreciated that the detected inelastic gamma rays are representative of the fast neutron population.

WHAT WE CLAIM IS:—

1. A method for determining the porosity of earth formations in the vicinity of a cased well borehole, comprising the steps of:

irradiating the earth formations in the vicinity of the cased well borehole with fast neutrons from a source of fast neutrons passed into the borehole;

generating a signal representative of the fast neutron population present in the well borehole at a location in the borehole spaced from said fast neutron source;

detecting the epithermal neutron population at a location spaced from said neutron source in the borehole and generating a signal representative thereof; and

combining said fast and epithermal neutron population representative signals to derive a measurement signal functionally related to the porosity of the earth formations in the vicinity of the borehole.

2. A method according to claim 1, wherein said fast neutron population location in respect of which said representative signal is generated and said epithermal neutron population detection location are at substantially the same distance from said neutron source in the borehole.

3. A method according to claim 1 or claim 2, wherein said combining step is performed by forming a ratio of said fast neutron and said epithermal neutron representative signals.

4. A method according to claim 3 and further including the step of calibrating said ratio signal according to a predetermined functional relationship to derive a porosity signal quantitatively representative of the porosity of the earth formations in the vicinity of the borehole.

5. A method according to any one of claims 1 to 4, wherein said irradiating step comprises continously irradiating the earth formations with fast neutrons from a continous neutron source.

6. A method according to claim 5, wherein said irradiating step is performed with a chemical type continuous neutron source.

7. A method according to claim 5, wherein said irradiating step is performed with a deuteruim-tritium accelerator type continous neutron source.

8. A method according to any one of claims 5 to 7, wherein said fast neutron representative signal generating step includes detecting fast neutrons by means of a stilbene scintillation detector for fast neutrons, and wherein said detector response to fast neutrons is distinguished from said detector response to gamma rays by pulse shape discrimination.

9. A method according to any one of claims 1 to 4, wherein said irradiating step comprises:

repetitively irradiating the earth formations with relatively short duration bursts of fast neutrons; and wherein said fast neutron representative signal generating step comprises:

detecting, substantially only during each said neutron burst, the fast neutron population present in the well borehole and generating said signal representative thereof.

10. A method according to claim 9 including the steps of:

detecting, substantially during each time interval between said repetitive neutron bursts, the background radiation present at said fast neutron detection location due to lingering